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(54) Cellular telephone satellite system.

(57) A cellular telephone system contains a satellite constellation formed of a plurality of telecommunications satellites (1) to provide an RF communication link with mobile cellular (3,5) and fixed telephone stations (7) within a geographical region. At all times at least one of such satellites (1) is visible from the predetermined region at an elevation of no less than ten degrees. The RF propagation delay between such visible satellite and said cellular station is no greater than 60 milliseconds. The satellite's orbits do not extend in altitude above the planet beyond altitudes referred to as medium earth orbit, characterized by 4,000 to 10,000 nautical miles. Suitably the number of orbital planes is no less than three and the satellites are evenly divided between the orbital planes.

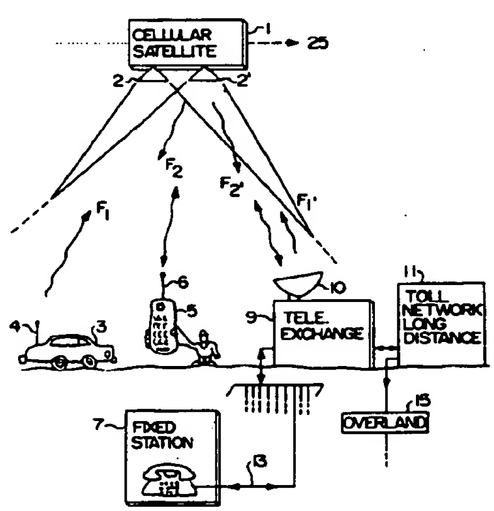

FIG. 1

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Field of the Invention.

The present invention relates to telephone communications systems and, more particularly, to a cellular telecommunications system containing a novel constellation of telecommunications satellites.

Background.

Cellular telecommunications systems allow a mobile telephone user to selectively communicate with other users at fixed land based telephone stations served by the central telephone network and with other mobile stations similarly served. This includes both local and long distance calls. The telephone link between the mobile and land based central telephone exchange is wireless; the communication link is radio frequency energy, "RF", typically in the ultra high frequency range. The cellular telephone system takes advantage of RF technology inherent in radio communications and broadcasting to transfer information in electronic form from one selected location to another without using telephone wires between the two locations. In voice communication, the RF serves as a carrier that is modulated with the users voice, an audio frequency, spoken into a microphone. At the other connected station, the RF carrier is received and demodulated to produce an audio signal. That audio signal is fed to a small loudspeaker which reproduces the original speakers voice at that location. Though the cellular link is RF, the cellular portion of the telephone system is integrated with remaining portions containing telephone lines and conventional telephone equipment.

Telephonic communication systems, including cellular, moreover, as distinguished from broadcasting systems, allows the user at any one station, the calling station, to selectively establish a telephone connection or link with another station, the called station, from among millions of possible stations in the systems to allow bilateral communication with the called station. The called station is selected by dialing its telephone number. Hence a dial switching and routing network equipment that responds to the callers "dial pulses" to establish the link to the called station represented by the dial pulse information, is characteristic of all telephone systems. In many countries, moreover, telephone systems are typically commercial in character. Hence, the customer accordingly must be billed and pay for the call that was placed. The amount of the billing statement for the call depends principally upon time and distance for the call and related taxes imposed by government. Thus billing equipment for determining and printing the customers bill for a call is also characteristic of telephone systems. Those equipment features of telephone systems presented here as background are known to the skilled reader and need not be discussed at length. Those features are understood as being implicit within the present cellular system, even though not discussed in further detail.

All such cellular telephone systems known to applicants are land based. That is the mobile cellular station is linked to the central telephone exchange by means of local land based stations, some of which may be located at the central exchange, that are capable of transmitting RF to and receiving RF from the mobile station within the range of coverage. These fixed land based cellular equipment, as serve to interact with the mobile unit, are for the most part located atop tall buildings or towers at various locations in, say, the community so as to be better accessible to signals from the lower power mobile station.

Governed by commercial cost and profit considerations, existing cellular systems provide mobile voice communications within the most populous areas of the U.S.A. and Europe. Other areas within those countries are essentially excluded by the poor economics. Thus cellular systems are not presently offered in other geographic areas of the world that are more sparsely populated, even though the population in total over those areas is significant. Much as the high cost of installing copper wire lines over long distances precluded private telephone business from extending the telephone line of ordinary telephone systems to the rural areas of the U.S.A. in the early part of the twentieth century until government incentives were provided, like economic consideration stalls private concerns from the introduction of existing cellular technology into such more sparsely populated areas. Progress in adding cellular system installations to those other geographic regions awaits more positive economics. Either government incentives must be provided, usually for reasons unrelated to economics, the cost of existing cellular technology falls as a consequence of higher volume production, or newer more lower cost technology is developed which makes installation of cellular systems in the more sparsely populated regions of the world commercially feasible.

To the latter end, an aspect of the present invention, as becomes apparent from reading this specification, has the advantage of providing an improved technology that is particularly able to serve more sparsely populated areas with cellular telephone communications on a commercially feasible basis, while also serving the more populated areas.

To achieve this advantage, the invention employs novel communication satellite constellations; that is geometric arrangements of a number of telecommunications satellites in relative spaced positions about the

planet. Telecommunications satellites traveling in geostationary orbits are found in current use in long distance toll telephone networks. They provide telephone links that extend over long distances, such as spanning the oceans. Geostationary satellites orbit the earth with the same 24 hour period within which the earth rotates on its axis; the satellite is geosynchronous. Moving thus with the same speed as the earth, to an observer on the earth the satellite appears to remain stationary. In many instances those geostationary satellites provide an alternative link to the underseas fiber optic telephone cables and in other instances the satellites may be the only link. Unfortunately each such satellite is possible of only limited coverage of the earth.

The cellular system of the present invention also employs telecommunications satellites which are placed in selective non-synchronous orbits about the earth. And the latter may be used in conjunction with other communications links for long distance intercontinental communications.

Mobile satellite communications for ships and some aircraft are presently available with INMARSAT, owned by the International Maritime Satellite Organization. Satellite systems of the American Mobile Satellite Company and that Of Telesat Mobile, Inc. are understood to be in development. Geostar, Locstar are systems to provide mobile communications. Eutel Tracs is a system which will allow surveillance tracking of vehicles. When completed and launched within the next five years, such systems will offer mobile communications in North America. The foregoing proposed systems all use geostationary satellites and, hence, require heavy, bulky and costly mobile transponders.

Although regular telephone users of international telephone service recognize the substantial achievements made in telephone communications between the major industrialized countries in more recent years, particularly in achieving satisfactory audio volume and clarity of voice in voice communications, not everyone is entirely pleased with all aspects of those communications. In those telephone calls one notices that one cannot easily interject a comment in a conversation; there is a time delay, typically on the order of a quarter of a second, two hundred and fifty milliseconds, between the sending of a sound at one telephone station and its receipt at the remotely located second station. Thus the conversation becomes more difficult, perhaps annoying to some. And telephone users are not quick to adapt to that annoying propagation delay. Since most telephone calls are local in nature and, in those telephone calls a perceptible delay does not occur, the ordinary user is effectively trained for the protocol of local telephone calls, training which is difficult to "shake" for the occasional long distance call. Because of the one quarter of a second propagation delay occurring at the 19,323 nautical mile geostationary altitude, the "one hop" time, the voice transmission quality of the foregoing geostationary satellite systems is perceived as degraded in comparison to that available on the local telephone toll network and even degraded in respect to the land based underseas telephone repeater cables. extending perhaps 10,000 mile between continents. Although endured in international communications, the annoyance is undesirable and should be avoided in local calls. As an advantage, the present invention avoids introducing the extended time delay inherent in geostationary satellites.

Others have sought to address that propagation delay. The Motorola Company, Schaumberg, Illinois, recently announced a worldwide mobile cellular communications system, named Iridium, which uses telecommunications satellites placed in non-stationary orbits. Though exact details of the proposal are not known and the system has not as yet been placed into practice some of the general aspects of that proposal are worthwhile considering further. The Iridium system is to employ seventy seven separate communications satellites that are placed in "low earth" orbit, that is circular orbits whose altitude from the surface is only four hundred and thirteen nautical mites. Each satellite will have the capability of communicating with another satellite as necessary to achieve the communication link. As the distance between a satellite in the Iridium constellation and a cellular station on the ground is low relative to a higher altitude geosynchronous satellite, the RF propagation time from one telephone station to another is less. As a result, the time delay in voice transmission between stations in that system should be imperceptible. With imperceptible time delay, the voice transmission quality in the Iridium system would thus appear high in contrast to those which incorporate geostationary satellites. The telephone user may converse with another in the ordinary manner as learned on existing local land based telephone networks. It may be noted that an advantage to the present invention is that the delay time described for geostationary satellites is substantially reduced and, in most cases, like in the proposed Iridium system, is not perceptible.

The proposed Iridium system requires large numbers of satellites. The system, moreover, is complex and costly, considering the launching of a large number of satellites and in operation is expected to require frequent changing of the crosslink configurations between the satellites.

Independent of any particular application, a number of investigators theretofore presented mathematical studies of potential satellite constellations to determine the minimum number of satellites as would provide single or double coverage of all locations on this earth. One of those investigators was Mr. J. G. Walker

and, accordingly, some circular constellations are sometimes referred to as Walker constellations. Walker generally defines constellations for satellite in a Report entitled "Continuous Whole-Earth Coverage by Circular-Orbit Satellite Patterns", Technical Report 77044 prepared for the Royal Aircraft Establishment, March 1977, available from the Defense Technical Information Center ("DTIC"). One is impressed with the large number of satellite constellations as might be defined for minimum satellite numbers and at least single whole earth coverage using Walker's criteria. Another investigator was Mr. John E. Draim who determined that the minimum number of satellites in a specific constellation of his definition capable of providing worldwide coverage was four. Draim thereby reduced by one the minimum number of five satellites, earlier thought to be the minimum in accordance with a prior mathematical criteria defining a different constellation.

As example in U.S. 4,854,527 granted August 8, 1989, as made known to applicants following the present invention, Draim prescribes a four satellite constellation that provides world wide coverage in which the satellites travel in four separate elliptical orbits, each with the same period, with those satellites at all times defining a tetrahedron, no side of which intersects the earth.

Although the foregoing work of Walker and Draim are of interest in their goals and analysis, they do not address the specific requirements of cellular communications systems. Not unexpectedly, the satellite arrangements those authors present for their specific purposes, although similar, would not be expected to be the same as in the present invention.

The present invention combines the benefit of mobile cellular telephones with the technological advantage of the space borne communications satellites. Accordingly, a principal object of the invention is to describe new satellite constellations for a cellular telephone system for permitting direct access by the mobile cellular station and for permitting telephone conversations to be carried on between stations in at least local zones or regions without annoying time delays between transmission and reception of voice messages. And a further object of the invention is to provide mobile cellular telephone system capable of hemispheric and worldwide coverage, both in heavily populated regions and sparsely populated regions, on a cost effective quality basis.

Summary of the Invention.

In accordance with the foregoing objects the present cellular telephone system contains at least one mobile cellular telephone station and at least one a fixed telephone station, spaced apart from one another within a predetermined region of a substantially spherical planet, such as the earth; a satellite constellation formed of a plurality of telecommunications satellites provides an RF communication link for the cellular and fixed telephone stations in that predetermined region. From within such region at least one of such telecommunications satellites is visible from each station at an elevation of at least ten degrees. The maximum RF propagation time between either station to such visible satellite is no greater than 60 milliseconds. The satellite constellation is further characterized by a plurality of telecommunications satellites orbiting in orbital planes about the planet whose orbits do not extend in altitude above the planet beyond altitudes referred to as medium earth orbit, 4,000 through 10,000 nautical miles. Suitably the number of orbital planes is no less than three and the satellites are evenly divided between the orbital planes.

The orbits may be circular or elliptical. In a more specific aspect to the invention, the constellation is formed of twelve satellites arranged in three orbital planes of four satellites each. Within each orbital plane the four satellites are evenly spaced and travel in the same direction and at the same velocity in a circular shaped orbit at an altitude of 5,600 nautical miles above the planet. With such constellation each user worldwide receives double coverage. In still another aspect elliptical orbits are formed which provide hemispheric coverage.

The foregoing and additional objects and advantages of the invention together with the structure characteristic thereof, which was only briefly summarized in the foregoing passages, and additional structure, becomes more apparent to those skilled in the art upon reading the detailed description of a preferred embodiment and the accompanying claims, which follows in this specification, taken together with the illustration thereof presented in the accompanying drawings.

Brief Description of the Drawings.

In the Drawings:

Figure 1 illustrates in symbolic form a cellular telephone system containing the invention;

Figure 2 symbolically illustrates a telecommunications satellite constellation having circular orbits for

single coverage used in connection with the embodiment of Fig. 1;
Figure 3 symbolically illustrates another form of the satellite constellation of Fig. 2 to provide double coverage;
Figure 4 illustrates a different form of constellation having elliptical orbits to provide single coverage used in the cellular system of Fig. 1; and
Figure 5 illustrates a different form of the constellation of Fig. 4 to provide double coverage.

Detailed Description of the Preferred Embodiments.

The present system is partially illustrated symbolically in figure 1 within a telecommunications system to which reference is made. A cellular telecommunications satellite 1 is shown moving in orbit traveling to the right at an appropriate velocity. The satellite carries down looking antennas 2 and 2' for transmitting and receiving, respectively, RF signals from land based cellular telephone equipment.

As represented in the figure, a mobile cellular station is carried within vehicle 3 and has cellular access via omnidirectional antenna 4; a hand held transportable cellular station 5 is carried by an individual and that station accesses cellular communication via omnidirectional antenna 6; and a fixed telephone station is represented in block 7. Each of those ground based elements in the region illustrated has satellite 1 in view at an elevation angle of at least ten degrees. Those elements are within the satellites coverage. The telephone exchange 9 is represented as containing also the cellular communications equipment, signified by antenna 10. Telephone exchange 9 accesses fixed station 7 via land based telephone line 13 and may access many other fixed stations, as is conventional, over additional telephone lines as is partially generally illustrated in the figure. The central telephone station has access to long distance circuits as well through a long distance toll network 11. Toll network 11 is responsible for selecting the appropriate circuits to permit access to the called party and may be carried out, depending on the called parties location over overland telephone lines, represented as 15. It is recognized that additional mobile cellular stations are included in the cellular system, but need not be illustrated.

As is apparent, satellite 1 is one of a number of satellites in a constellation hereafter discussed in greater detail with respect to subsequent figures and is the one of the satellites in that constellation that is traveling at a height of 5600 nautical miles in altitude above the earth in a circular orbit, as example, providing RF coverage to the underlying stations illustrated. As the satellite moves out of range of view of the ground based stations, another satellite of the constellation enters the range and take its place, the latter thereafter providing the same function in the cellular system communication link as the former. This is hereafter described in greater detail.

At a minimum, a telecommunications satellite is designed to receive RF of one frequency band, say F1, at its receiving antenna from a geographic area over which the satellite has coverage, translate that to an intermediate frequency, IF, and amplify that IF, and then convert the signal to another frequency for output, say F2, at a transmitting antenna to the same geographic area. It is effectively a repeater, characterized by some as a "dumb" satellite, and does not attempt to obtain the base band information, the voice, data and/or switching messages that are contained in the incoming RF. Other more sophisticated or "smart" satellites, as those skilled in the art appreciate, may do more. Some satellite designs may include multiple RF output beams independently directed to selected portions of the covered area. In those designs the incoming signal is processed within the satellite to decode the baseline information to determine whether the station to be reached is in the area of the first or second beam and then select the appropriate beam for output.

When an RF carrier is modulated, the modulation often carries information, whether that information is analogue audio information, such as the spoken word, or digitized audio information, or digital data signals. The content of that information is the meaning which the spoken word conveys and/or the substance that the data is intended to reveal. As example the telephone number of the called station is sent by pressing the dial keys. All such information may be referred to as "baseband" information. As example, the telephone exchange demodulates the RF and extracts the baseband information and then processes and acts upon that information, in the case of a dialed number, by establishing the connection to the called station.

Presently available "dumb" satellites capable of working in this invention may have output powers and, importantly, receiving sensitivity and antennas, which permits reception of mobile cellular signals generated with power levels as low as one half watt emitted from an omnidirectional antenna and transmission to that mobile station. Design considerations for achieving satellites with those characteristics are known. As recognized by those skilled in the art, the power requirements for both transmitting and receiving for quality transmission depend greatly upon antenna size; the larger the antenna the better the transmission. Certainly

telecommunications satellites used at geostationary altitudes have RF power of 600 watts with those antennas may be used in the present system. For the satellites of the disclosed systems the satellite launch weight will range from 2400 to 3000 pounds. Its power consumption will be on the order of 2,600 watts, of which 1,500 watts is for the downlink transmitters to the mobile units. The satellite contains an antennas of appropriate size to enable communication with one half watt power mobile cellular stations and for communication with the ground based stations.

It is noted that present communications protocols call for "down link" transmission from the satellite, F1, to be in the range of frequencies of 1.4 - 1.5 GHz and "up link" transmission to the satellite from a mobile station, F2, to be in the range of 1.5 to 1.6 GHz. Both such frequency ranges are commonly referred to as L-Band frequencies. A different choice of frequencies is prescribed for the communications link to a fixed station, such as the telephone exchange 11, which are in Ku-Band. For that down link the frequency, F1, is 11.7 to 12 GHz in range and the associated up link frequency, F2, is 14 to 14.5 GHz. And while transmissions to and from individual stations have been referred to generally as F1 and F2 it is understood that the frequencies of those stations, through falling within the same prescribed range of frequencies, differ at least slightly so as to avoid interfering with one another. Those different frequencies within the band are assigned by the telephone company to the stations.

Thus telecommunications satellites of existing design may be used in the present system. The present invention encompasses within its scope any type of telecommunications satellite, either smart or dumb Those skilled in the art recognize that the present invention is not dependent upon the kind or type of telecommunications satellite employed and does not depend upon any particular kind of special satellite structure or details. Accordingly, those known details of known telecommunications satellites need not be here further described.

It is appreciated that the foregoing symbolic illustration of the telephone system is very simplified and does not detail, even in block form, the various known forms of equipment found in conventional practice in the system to carry out all aspects of long distance or local call switching and routing selection circuits and billing equipment and the like, which are implicitly present in the system, as such detail is not necessary to an understanding of the invention and would serve to obfuscate a clear understanding of the present invention.

In operation of the system presented in Figure 1, should a person initiate a telephone call from mobile unit 3 by going "off hook", the station sends RF at frequency F1, modulated to indicate an off hook condition. That RF is directly picked up by the satellite then covering the area, satellite 1 in the illustration, which picks up the signal at antenna 2. The satellite in turn translates and sends a signal via antenna 2' at frequency F2 to the underlying telephone exchange 9 via the latter antenna 10. When a circuit is available, usually almost instantaneously, exchange 9 signals back to the satellite and the satellite in turn via the same frequency F2 sends a code which permits station 3 to dial another station, as by punching in the "touch tone" keys on the callers station. The satellite in turn receives that information as a form of modulation on the RF at carrier frequency F1. and, in the situation of a standard telecommunications satellite, translates and retransmits that information at carrier frequency F2 to the telephone exchange. Telephone exchange 9 thereupon sets up the connection to the called party using conventional circuits, the details of which are known to those skilled in this art and need not be here presented.

The called station, for example, may be fixed station 7, in which event the exchange establishes a connection. does the conventional test of the fixed stations lines for a busy condition, and, if available, supplies a suitable ringing current over telephone line 13, which causes the called parties telephone to produce an audible signal, to ring. When the called party answers at fixed station 7, the person speaks into the telephone transmitter, the microphone, and that audio message is transmitted over the telephone line to the telephone exchange. In turn the telephone exchange applies that audio signal as modulation to the carrier of its RF transmitting equipment and transmits that at F1 to the satellite. In conventional manner satellite 1, translates that to frequency F2 and downlinks same over the area covered, an area which includes mobile station 3 and also includes the telephone exchange 9 which sent the signal and now discards it.

A conversation may then be carried on between persons at mobile station 3 and fixed station 7. The audio modulated RF signal from the mobile station travels up to the satellite and then down to the exchange and station 7 in a single "hop" and vice versa with audio voice messages originating at station 7, resulting in a slight propagation delay as is elsewhere herein discussed in greater detail.

If instead of fixed station 7, a user at mobile station 3 desires to call mobile station 5, the interrelationship of the elements is somewhat different. In this situation telephone exchange 9, detecting a call to another mobile station, transmits station 5's frequency as modulation on carrier F2. Satellite 1 receives, translates and essentially broadcasts that signal in the covered area, which includes the area

containing station 5.

Through local circuits in exchange 9, the exchange checks station 5 for a busy condition and on finding the station available issues an appropriate code that in turn causes a ringing signal at station 5. The exchange transmits the code as modulation on the RF carrier F1, which the satellite translates as before to RF carrier F2 and broadcasts that signal, F2, in the covered area below. Station 5 recognizes its code and actuates an audio circuit within the station that is emitted to signal an incoming call. In short, the telephone rings. Upon actuating station 5 to receive the call, the two mobile stations are placed into a communications link, allowing bi-lateral communications. In this case, the modulated frequencies emitted by mobile station 3 travel to the satellite and from there to exchange 9. In turn the exchange routes the signal back out of its antenna 10 to satellite 1, which in turn again broadcasts that signal to the other mobile station.

As is apparent the audio messages entered by the calling party takes two trips to the satellite and the central exchange, a "double hop", before being received at the second mobile station. This effectively doubles the propagation time and the time delay in comparison to the prior example with a fixed station. Even with such a "double hop" the propagation delay is less than that which occurs through use of a satellite at geostationary altitudes.

It is noted that it is possible to eliminate such a double hop in a mobile to mobile communication by modifying the system to incorporate a particular type of smart satellite. In such satellite a processor would check the baseband information in the dial signal pulse train and check if a mobile station was being called. Should that be the case the processor would check its memory and transmit the telephone signal direct. The call would then be completed in a single hop.

Propagation delay is related to the satellites height above the earth. As RF travels at essentially the speed of light, the higher the satellite, the greater is the propagation delay. With the present invention, the propagation delay from a cellular station to the satellite in view is no larger than 60 milliseconds; the propagation delay from the satellite down to the earth based exchange is also no larger than 60 milliseconds. The single hop transmission time, thus, is no greater than 120 milliseconds. As example at the 5,600 nautical mile altitude the one hop propagation time from two stations both located essentially underlying the satellite is 69 milliseconds; while the maximum propagation delay of two stations spaced apart at the minimum elevation angle of ten degrees is 96 milliseconds.

The relationship between station to station propagation time and satellite altitude in a single hop from the ground station to the satellite and back again to ground, with the maximum range occurring when the satellite is at a minimum elevation of ten degrees, may be shown as follows:

Satellite Altitude (n.mi.)	Maximum Terminal to Satellite Propagation Range (n.mi)	Maximum Terminal to Terminal Propagation Time (m.sec.)
4500	6564	81
5000	7113	88
5500	7656	94
6000	8191	101
6500	8724	108
7000	9255	115
7500	9782	121

Coverage denotes the geographic region which may be effectively handled by the RF reception and transmission characteristics of the particular satellite, the underlying regions on a planet, the earth, to which the satellite is capable of communicating with. As example if one were distant enough from the earth and considering line of sight, one would visually cover a hemisphere. As one moved the satellite lower to the earth, one then could only view of portion of a hemisphere. The same holds true for a satellite containing a given antenna and receiver sensitivity as the satellite is moved closer to or farther from the earth. Of course, by making the satellites antennas highly directional, then the more limited the region that the satellite may cover.

The present system employs a constellation of satellites with the satellites thereof located in three inclined orbit planes. The orbital planes are evenly spaced about the planet with their ascending nodes, which are taken at the earth's equator, 0 degrees latitude, being 120 degrees apart. The maximum distance above the earth attained by any orbit is in the range between 5,000 and 10,000 nautical miles above the earth, which is referred to as "medium earth" orbit.

With a circular orbit the satellites remain within the medium earth orbit range at all times. However with an elliptical orbit, as later described, the satellites remain in that range for a portion of the time and at other

times in their periodic travel they travel within the range referred to as lower earth orbit. As example, in one elliptical orbit, discussed hereafter, the apogee altitude is 6300 nautical miles and the perigee altitude is 600 nautical miles above the earth.

Considering a first constellation in greater detail, as generally illustrated in Figure 2, a series of 9 telecommunications satellites, which are of conventional structure, labeled 1a-1c, 2a-2c, and 3a-3c, are evenly divided between and arranged in three orbital planes. P1, P2 and P3, illustrated by the circles about planet E, representing the earth. Three of the satellites, 1a, 1b and 1c, are located in orbital plane P1 and travel at the same velocity and in the same direction in the same circular orbit. Those satellites are evenly spaced from one another by 120 degrees of arc.

Each satellite travels in a circular orbit of altitude above the earth of 5600 nautical miles. One of the satellites is hidden from view behind the planet and is represented in dotted lines. Each orbital plane is inclined at an angle of 55 degrees relative to the equatorial plane of the earth, represented as zero degrees latitude. The ascending node spacing is 120 degrees. Satellites 2a, 2b and 2c in plane P2 and Satellites 3a, 3b and 3c in plane P3 are the same. Within each orbit the satellites are evenly spaced apart, travel at the same velocity and at the same altitude of 5600 nautical miles above the earth. Except for the different planes and relative phasing the three orbits are otherwise identical.

The relative phasing angle between satellites in adjacent orbit planes is 80 degrees. Thus before one satellite in the constellation disappears from view, as observed from a covered location on earth, at least one additional satellite comes into view above an elevation angle of ten degrees. The minimum ground elevation angle is ten degrees. The foregoing constellation provides global coverage with single coverage for each location on the earth.

To provide double coverage globally using the three circular orbits of the preceding example, the number of satellites in each orbit is increased by one to provide a total of 4 satellites per orbital plane spaced apart 360/4 or 90 degrees; a total of 12 satellites. This is illustrated in Figure 3 in which the designations given to the elements of Fig. 2 are retained to assist in understanding the subject. This figure contains satellites 1a-1d, 2a-2d and 3a-3d. The relative phasing between satellites in adjacent orbit planes is 90 degrees. That is, the phasing between satellites 1a and 2a is 90 degrees, between 2a and 3a is 90 degrees and so on. The remaining elements defining the orbits in this example are the same as in the foregoing example.

If global coverage is desired circular orbits are preferred. If however only a hemisphere of coverage is desired then a constellation of elliptical orbits is preferred. These additional constellations for hemispheric coverage are illustrated in Figures 4 and 5 in which for convenience like designations, but containing an additional prime symbol, are used for corresponding elements previously described. As example a preferred elliptical orbit for coverage in the earth's Northern Hemisphere, particularly for latitudes 20 degrees north to 90 degrees north, with single coverage would include six satellites in three orbit planes with two satellites per plane as illustrated in Figure 4.

The orbit is defined by an Apogee altitude of 6300 nautical miles, a perigee altitude of 600 nautical miles, a plane inclination of 63.4 degrees, an ascending node spacing of 120 degrees, an argument of perigee of 270 degrees and a relative phasing angle between satellites in adjacent orbit planes of 180 degrees. The minimum ground elevation angle is taken as ten degrees.

For double coverage of the Northern Hemisphere, the number of satellites in the preceding constellation is increased by three, and the number of satellites per orbit plane is increased to three as is illustrated in the constellation presented in Figure 5. In that case the relative phasing angle between satellites in adjacent orbit planes is 180 degrees. The remaining orbit parameters of apogee, perigee, inclination, and ascending node angle are the same as in the preceding case. A minimum ground elevation angle is also taken at ten degrees.

In the latter elliptical constellation at the 6,300 nautical mile altitude apogee the one hop propagation time from two stations both located essentially underlying the satellite is 78 milliseconds; while the maximum propagation delay of two stations spaced apart at the minimum elevation angle of ten degrees is 105 milliseconds.

The foregoing constellations are conveniently tabulated in the table which follows in this specification.

Constellation				
	Coverage			
	Global		Northern Hemisphere	
	Single	Double	Single	Double
Number of Satellites	9	12	6	9
Number Orbit Planes	3	3	3	3
Satellites per Plane	3	4	2	3
Apogee Altitude(nm)	5600	5600	6300	6300
Perigee Altitude(nm)	5600	5600	600	600
Inclination(degrees)	55	55	63.4	63.4
Ascending Node Spacing	120°	120°	120°	120°
Argument of Perigee	0	0	270	270
Relative Phasing between Satellites in Adjacent Orbit Planes.	80°	90°	180°	120°
Minimum Ground Elevation Angle	10°	10°	10°	10°

The coverage afforded by circular and elliptical orbits differs significantly. Circular orbits do not favor either northern or southern latitudes and therefore tend to provide global coverage. Elliptical orbits favor one or the other portion of the globe. If one is interested thus in limiting coverage to the northern latitudes then the elliptical orbit may be preferred. By placing the apogee at the northernmost latitude reached by the satellite, which is equal to the inclination, the coverage period for the northern latitudes is maximized. The same coverage, single or double may then be provided to those latitudes with fewer satellites.

In low earth orbit or in an elliptical orbit whose perigee falls close to the earth, such as under 4000 nautical miles altitude, the satellite encounters the Van Allen radiation belt. This region is characterized by harmful radiation. Hence satellites which progress through the radiation belt must be protected from that radiation to prevent premature failure of electronic equipment, particularly semiconductor circuits. As a consequence, satellites that are placed in the elliptical orbit called for in the alternative embodiment are heavier.

In the foregoing constellations, the satellites, as seen from a fixed ground location, move across the sky. As one satellite moves off the horizon, at least one other satellite will have appeared in view at or above an elevation of ten degrees.

The much lower than geostationary altitude or the present constellations reduces the transmit power requirements on both the satellite and on the ground, while permitting high quality telephonic communication. With a telecommunications satellite having a conventional size antenna the present systems allows hand held mobile cellular stations containing omnidirectional antennas to employ as little as one half watt RF power, which is the power level of the most compact hand held units currently being marketed in the U.S.A. By contrast a one half watt cellular station used with a geostationary satellite would require an extremely large satellite antenna at the L-band mobile frequencies currently allocated by the U.S. Federal Communications Commission.

An advantage to the present invention is that the practical implementation may be accomplished in at least two stages, with the latter stages providing enhancement of the system as a result of actual experience learned when the system is operational. Thus the constellation of Figure 2 may be formed initially with nine satellites and, thereafter, the system may be expanded by an additional three satellites to provide a minimum of double coverage on a worldwide basis to attain the constellation of Figure 3.

The small number of orbit planes required by the present system initially affords considerable flexibility in launching. Up to three satellites can be combined in a single launch resulting in a less expensive installation.

The satellites carry thrusters that are controlled by appropriate ground control stations. Thrusters are conventional positioning and control accessories and assist in the assembly of the constellation, permitting the ground control to retard a satellite or to accelerate a satellite, to move it forward or backward in the orbit. Thus as example in the assembly of the described constellations, three satellites may be carried aloft in a single launch vehicle, such as a rocket or engine, and released at a single point in orbit. The ground

control may operate the thruster on a first satellite to cause it to slow it down. while the thruster of the third satellite is operated to push forward. Thereby the three satellites may be positioned apart 120 degrees about the periphery of the same circular orbit after being dropped off together by the launch vehicle. With three separate orbits, of course, the groups of satellites are carried aloft in at least three separate launch vehicle and positioned in the aforedescribed manner or. alternatively if the launch vehicle is a re-useable one, such as a shuttle type, it is used on three different occasions to fill the three orbits.

An additional advantage of the latter constellation is that in the event a single satellite in the system fails, continued service would still be provided on a worldwide basis with a reduced number of telephone links possible, until the failed satellite is repaired or replaced and full service restored. As a satellites operational life depends upon its length of service in space flight, the addition of three satellites at a later date, also means that at least those three will continue in service beyond the end of operation life to the initial nine satellites, spreading replacement cost over time while always maintaining some portion of the system in service.

A unique advantage to the present system is that it is often possible to handle some intercontinental telephone calls in a single hop without the necessity of using the regular geostationary satellite or underseas cable as part of the link. More specifically the system permits a single satellite to provide coverage of an area containing a pair of points in Europe and North America or, alternatively, in North America and Japan. Thus an international telephone call is possible by satellite that does not have the inconvenient propagation delays of geostationary satellite systems.

In the preceding discussion telephony has been discussed in connection with transmission and reception of voice messages, the spoken words. However, as those skilled in the art appreciate audio signals other than voice messages are now applied to the telephone lines. As example, through use of accessory modems computer data may be sent as audio frequency signals over the telephone line. Likewise facsimile machines are coupled to the telephone lines by an associated modem and send copies of documents to a distant facsimile machine by means of audio frequency signals produced by the associated modem. Although voice messages are the principal driving force for cellular communications, it is understood that those additional examples using audio transmissions are included within the scope of telephonic communications as used in this specification.

It is believed that the foregoing description of the preferred embodiments of the invention is sufficient in detail to enable one skilled in the art to make and use the invention. However, it is expressly understood that the detail of the elements which is presented for the foregoing purpose is not intended to limit the scope of the invention, in as much as equivalents to those elements and other modifications thereof, all of which come within the scope of the invention, become apparent to those skilled in the art upon reading this specification. Thus the invention is to be broadly construed within the full scope of the appended claims.

Claims

1. A cellular telecommunications system, comprising:

   at least one mobile cellular telephone station, said mobile cellular station including means for transceiving RF;

   at least one fixed telephone station;

   a telephone exchange, including exchange RF transceiving means for transceiving RF and telephone lines for connecting said fixed telephone station in communication with said exchange transceiving means;

   said mobile cellular telephone and said fixed telephone stations being spaced from one another within a predetermined region of a substantially spherical rotating planet;

   telephonic satellite constellation means located in space over said planet for providing an RF communication link with said mobile cellular station and said telephone exchange, said telephonic satellite constellation means including RF transceiving means, whereby a communication path may be established between said mobile cellular station and said telephone exchange;

   said satellite constellation means comprising a plurality of telecommunications satellites, said satellites being spaced and moving in orbits about said planet with said movement of said satellites being non-synchronous to the rotation of said planet;

   at least one of said satellites being in the line of sight to both said mobile cellular station and said telephone exchange at any moment of time, with said line of sight being at an elevation of no less than ten degrees: with the maximum RF propagation time over said line of sight therebetween being less than sixty milliseconds; and all of said plurality of satellites being at an altitude from said planet of no more than 10,000 nautical miles at any moment of time.

2. The invention as defined in claim 1, wherein said orbits comprises three orbits of identical inclination with said orbits lying within three orbital planes evenly spaced about the planet and wherein said plurality of satellites is evenly distributed between said three orbits.

3. The invention as defined in claim 2 wherein each said orbit comprises a predetermined circular geometry of like altitude above said planet.

4. The invention as defined in claim 3, wherein said altitude of each said orbit comprises 5600 nautical miles.

5. The invention as defined in claim 3, wherein said inclination of said orbit is 55 degrees.

6. The invention as defined in claim 5, wherein said plurality of satellites comprises the number nine.

7. The invention as defined in claim 5, wherein said plurality of satellites comprises the number twelve.

8. The invention as defined in claim 2 wherein each said orbit comprises a predetermined elliptical geometry of like apogee altitude and perigee altitude above said planet.

9. The invention as defined in claim 8, wherein said apogee altitude of each said orbit comprises 6300 nautical miles and said perigee altitude thereof comprises 600 nautical miles.

10. The invention as defined in claim 8, wherein said inclination of said orbit is 63.4 degrees.

11. The invention as defined in claim 10, wherein said plurality of satellites comprises the number six.

12. The invention as defined in claim 10, wherein said plurality of satellites comprises the number nine.

13. In a cellular telecommunications system containing at least one mobile cellular telephone station and at least one fixed telephone station spaced apart within a predetermined region of a substantially spherical rotating planet, the combination comprising: satellite constellation means located in space over the planet and said stations for providing an RF communication link to said cellular and fixed telephone stations, wherein a communication path may be established between said stations; said satellite constellation means comprising 3N telecommunications satellites with said satellites being evenly divided between three separate substantially identical orbits of circular geometry, where N is a whole number that is at least 3 and no greater than 4, with each of said orbits being in an orbital plane inclined to the zero degree latitude of the planet by an angle of fifty five degrees, and with the ascending node of said orbits being spaced evenly 120 degrees apart about a midsection latitude of said planet and with all of said satellites traveling in the same direction, clockwise or contra clockwise of the planet, at the same periodic rate, non-synchronous to the period of rotation of said planet and at an altitude of 5600 nautical miles above the planet; and with at least one of said satellites in said constellation being visible from said mobile cellular station at an elevation of no less than ten degrees at any instant of time and with the RF propagation delay between any one of said satellites that is visible from within said predetermined region and said cellular station at any instant of time being no greater than 60 milliseconds.

14. In a cellular telecommunications system containing at least one mobile cellular telephone station and at least one fixed telephone station spaced apart within a predetermined region of a substantially spherical rotating planet, the combination comprising: satellite constellation means located in space over the planet and said stations for providing an RF communication link to said cellular and fixed telephone stations, wherein a communication path may be established between said stations; said satellite constellation means comprising 3N telecommunications satellites with said satellites being evenly divided between three separate substantially identical orbits of elliptical geometry, where N is a whole number that is at least 2 and no greater than 3, with each of said orbits being in an orbital plane inclined to the zero degree latitude of the planet by an angle of sixty three and four tenths degrees, and with the ascending node of said orbits being spaced evenly 120 degrees apart about a midsection latitude of said planet and with all of said satellites traveling in the same direction, clockwise or contra clockwise of the planet, at the same periodic rate, non-synchronous to the period of rotation of said

planet, with said elliptical orbit having an apogee altitude of 6,300 nautical miles and a perigee altitude of 600 nautical miles above the planet; and with at least one of said satellites in said constellation being visible from said mobile cellular station at an elevation of no less than ten degrees at any instant of time and with the RF propagation delay between any one of said satellites that is visible from within said predetermined region and said cellular station at any instant of time being no greater than 60 milliseconds.

15. The method of construction of a cellular telephone system that provides telephone communications over regions of the earth, which includes the steps of:

carrying into a first orbit in a launch vehicle at least one of a plurality of telecommunications satellites and releasing said carried satellites from said launch vehicle into a medium earth orbit at a predetermined orbit inclination angle;

carrying into a second orbit in a launch vehicle at least one of a plurality of telecommunications satellites and releasing said carried satellites from said launch vehicle into a medium earth orbit at said predetermined orbit inclination angle;

carrying into a third orbit in a launch vehicle at least one of a plurality of telecommunications satellites and releasing said carried satellites from said launch vehicle into a medium earth orbit at said predetermined orbit inclination angle;

said medium earth orbit being orbits having a maximum altitude within the range of 4,000 nautical miles in altitude above the earth to 10,000 nautical miles in altitude above the earth and with said first, second and third orbits being spaced apart by 120 degrees.

16. The method as defined in Claim 15 which further includes the step of operating thrusters on said satellites to position two or more satellites carried into a given orbit in orbital positions evenly phased from one another about said given orbit.

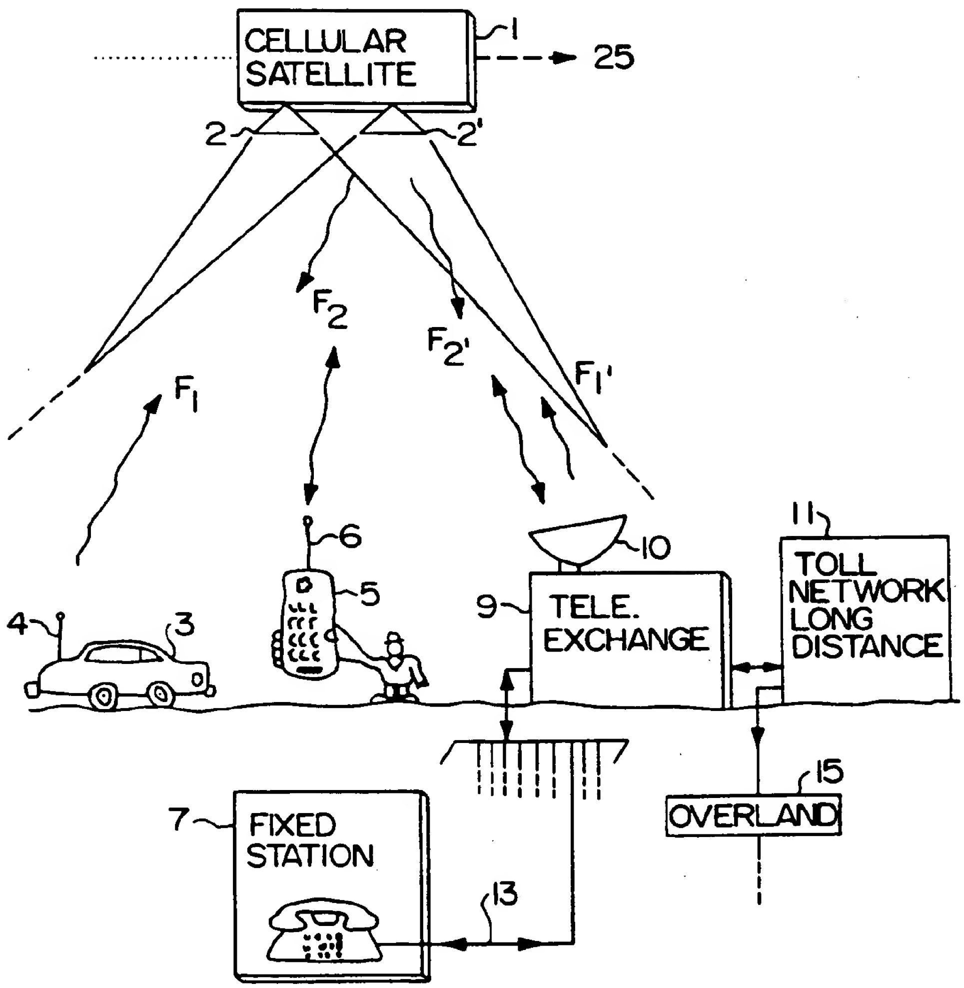
CELLULAR
SATELLITE
1
25
2
2'
F2
F2'
F1
F1'
6
5
10
4
3
9
TELE.
EXCHANGE
11
TOLL
NETWORK
LONG
DISTANCE
15
OVERLAND
7
FIXED
STATION
13

FIG. 1

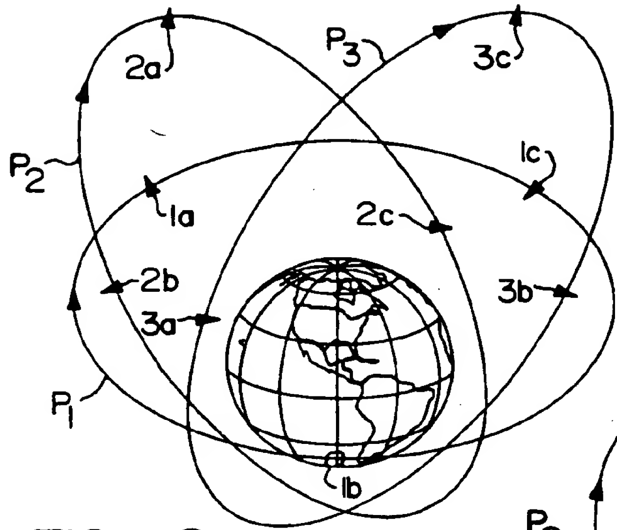

FIG. 2

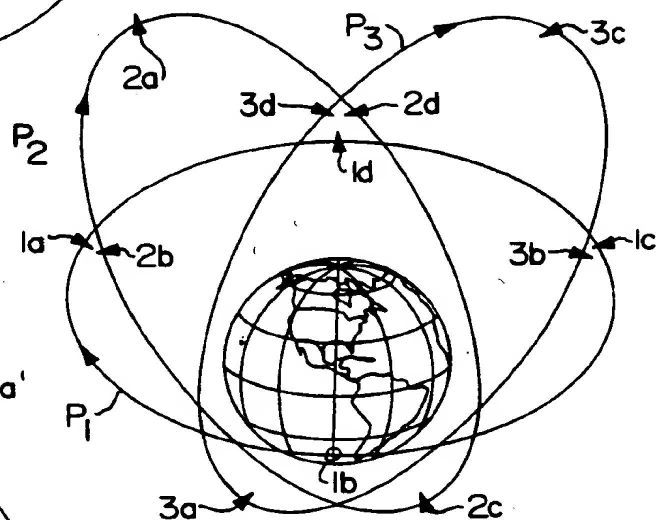

FIG. 3

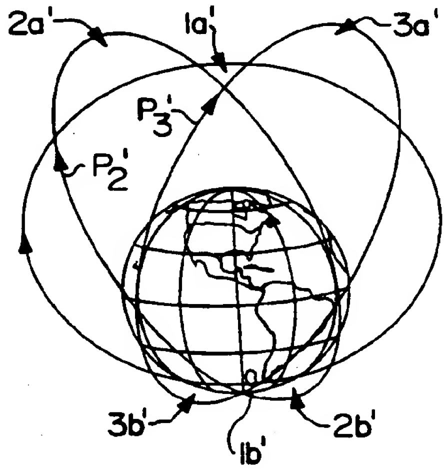

FIG. 4

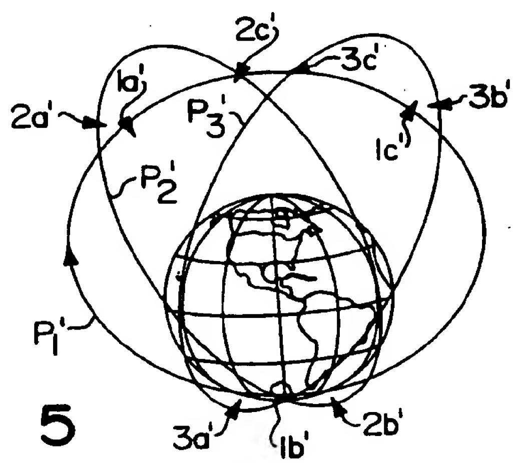

FIG. 5

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EUROPEAN SEARCH REPORT

Application Number

EP 92 30 0781

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y	EP-A-0 365 885 (MOTOROLA INC.)	1-4, 8-10, 13-15	B64G1/10 H04B7/195
A	* column 1, line 40 - column 2, line 5 *	5-7, 11-12,16	
	* column 2, line 28 - column 6, line 43; figures 1-4 *		
Y	EP-A-0 237 009 (SIEMENS AKTIENGESELLSCHAFT BERLIN UND MÜNCHEN)	1-4, 8-10, 13-15	
A	* column 2, line 35 - column 3, line 10 *	5-7, 11-12,16	
	* column 3, line 50 - column 4, line 44; claim 1; figures 1-4 *		
A	US-A-3 349 398 (WERTH, A.M.)	1-7, 13-15	
	* column 2, line 5 - line 49 * * column 4, line 1 - column 6, line 23 * * column 13, line 42 - line 55 * * column 15, line 57 - line 75; figures 1-2 *		**TECHNICAL FIELDS SEARCHED (Int. Cl.5)**
A	EP-A-0 331 567 (CENTRE NATIONAL D'ETUDES SPATIALES) * column 2, line 36 - column 3, line 63 * * column 4, line 19 - column 7, line 17; figures 1-7 *	1-2,8-16	B64G H04B
A	RCA REVIEW vol. 24, September 1963, PRINCETON, N.J., (USA) pages 293 - 324; D.G.C. LUCK: 'SYSTEM ORGANIZATION FOR GENERAL COMMUNICATION VIA MEDIUM ALTITUDE SATELLITES' * the whole document *	1-15	
	-/--		

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	30 JULY 1992	RIVERO C.G.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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D : document cited in the application
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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	US-A-3 497 807 (NEWTON, R.R.) * column 1, line 9 - line 25 * * column 1, line 56 - column 4, line 39; figures 1-3 * ---	1-7, 13-16	
A	US-A-3 340 531 (KEFALAS, G.P. ET AL.) * column 2, line 10 - line 55 * * column 4, line 59 - column 5, line 60; figures 1-3 * -----	1-2, 13-15	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
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D : document cited in the application
L : document cited for other reasons

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